ANALYSIS OF GREEN RATING FRAMEWORK FOR PRE-ENGINEERED STEEL BUILDINGS

SHORT SYNOPSIS

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Certificate

I, hereby declare that the short synopsis **"Analysis of Green Rating Framework for Pre-Engineered Steel Buildings"** being submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy in Civil Engineering under School of Engineering and Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2023 –24. It is a bona fide record of original work carried out under the supervision of **Dr. Sunita Bansal**, Professor, Department of Civil Engineering, School of Engineering and Technology, and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

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ABSTRACT

Green building concepts have gained significant attention in the coming years due to their inherent potential to mitigate environmental impacts and address climate change challenges. India, as a rapidly developing nation, is facing numerous sustainability challenges, including rapid urbanization, resource depletion, and high energy consumption. Consequently, the adoption of green building practices has become crucial to ensure a more sustainable built environment. Pre-Engineered Buildings (PEB) are prefabricated structures that are engineered and manufactured off-site, offering numerous advantages such as reduced construction time, cost-effectiveness, ease of installation, green project support and flexibility in design. Although they are being employed widely but their sustainability quotient and Green Rating framework is yet to be formalised. This research will explore the principles and practices of sustainable construction, with a particular focus on the integration of PEBs as a viable solution for achieving environmentally friendly and resource-efficient structures. The research methodology includes case studies, interviews with industry experts, and analysis of relevant PEB project data to assess the environmental, economic, and social aspects. The findings of this research will provide valuable insights into the potential of PEBs. Ultimately, this thesis aims to foster a more environmentally conscious approach to construction, where Green rating framework for PEB would be developed and recommended.

Key Words: Green Building, Sustainable development, GRIHA, Construction, Pre-Engineering Building (PEB).

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List of Abbreviations

Abbreviations	Description	Page No.
PEB	Pre-engineered building	1
AISC	American Institute of Steel Construction	1
AISI	American Iron and Steel Institute	1
IS	Indian Standard Codes	1
MBMA	Metal Building Manufacturers Association	1
IGBC	Indian Green Building Council	1
IGBC	Integrated Habitat Assessment	1
CAGR	Compound Annual Growth Rate	2
MBS	Metal Building Software	12

1. INTRODUCTION

1.1 Pre-Engineered Buildings

The building sector consumes substantial energy and more natural resources than any other sector. The government is putting more pressure on the building sector to reduce its environmental effects since there is a rising concern for the best use of natural resources given their scarcity. Adopting sustainable building practises has many advantages, even if there are some challenges.

Green building practices have emerged as a critical approach to address the environmental impacts of the construction industry. They emphasize sustainable design, energy efficiency, resource conservation, and the creation of healthy and comfortable indoor environments. As Green building practices have become increasingly important, there has been a growing interest in evaluating the environmental performance and energy efficiency of PEB [1].

Cost-effectiveness, speed of construction, and design versatility are just a few of the reasons why prefabricated or Pre-engineered building (PEB) have become more popular in the building industry [2]. This study aims to delve into the realm of PEB, focusing on their alignment with green building practices and their assessment under both world and Indian rating systems.

PEB offer great potential for incorporating green building practices due to their inherent flexibility in design, allowing for the integration of energy-efficient systems, renewable energy sources, and sustainable materials. In the design of PEB, codes IS 800 -2017, AISC manual of steel construction for allowable stress, AISI cold formed steel design manual and MBMA low rise building systems manual are used [3]. In the Manufacturing of PEB, codes AWS D1.1/D1.1M:2015 an American National Standard for structural welding code and MBMA manual for fabrication tolerances are used [4].

Global standards for sustainable building techniques have been established through rating systems like Green Star, Leadership in Energy and Environmental Design (LEED), and Building Research Establishment Environmental Assessment Method (BREEAM). These grading systems assess a building's sustainability in terms of a variety of factors, including energy efficiency, water management, material choice, interior environmental quality, and site sustainability. In order to demonstrate how PEBs may fulfil global sustainability criteria, the research will look at how they can complement and contribute to current grading systems.

In India, the Indian Green Building Council (IGBC) has developed the Green Rating for Integrated Habitat Assessment (GRIHA), a homegrown green building rating system. GRIHA focuses on assessing the environmental impact of buildings in the Indian context, considering

factors like site selection, energy conservation, water management, waste management, and indoor air quality. This study will also examine the applicability of PEBs within the framework of GRIHA, exploring how these structures can contribute to achieving GRIHA certification and promoting sustainable practices in the Indian construction industry [5].

By conducting a comprehensive study of PEBs in the context of green building practices and rating systems, this research aims to shed light on the opportunities and challenges associated with incorporating sustainable elements into PEB design, construction, and operation. The findings of this study can serve as a valuable resource for architects, engineers, developers, and policymakers seeking to enhance the environmental performance and energy efficiency of PEBs, thus fostering sustainable development in the construction sector [6].

According to the research done by Varsha More's et al. [7] the market size for pre-engineered structures in India was estimated at USD 18.8 billion in 2021. From USD 20.99 billion in 2022, the Indian pre-engineered building market is projected to reach USD 50.72 billion by 2030, expanding at a CAGR of 11.66 percent (2022 -2030).

According to the analysis, the rising demand for lightweight building structures and the increasing usage of pre-engineered buildings across a variety of end user sectors, including infrastructure, commercial, residential, and warehouses, are the main factors boosting market expansion.

1.2 Green Building Practices

Green construction is transforming India's future. Green buildings have grown in popularity as environmental issues and sustainable development are recognised. These approaches improve building environmental performance, resource efficiency, and carbon emissions. India is improving its built environment and tackling environmental issues by embracing green construction principles [8].

Energy Efficiency and Renewable Energy

Green architecture in India emphasises energy efficiency to decrease carbon impact. Use energy-efficient appliances, lights, and insulation. Solar panels are incorporated into building designs to provide clean, sustainable energy on-site.

Water Conservation and Management

Green architecture requires water conservation due to India's water shortage. Green buildings include rainwater collection, greywater recycling, and water-efficient plumbing equipment. These strategies help water resources last.

Sustainable Material Selection

Green architecture emphasises eco-friendly materials. To decrease transportation emissions, use locally produced, low-embodied energy, recyclable, or renewable products. Green buildings use environmentally friendly materials throughout their lifespan.

Waste Management and Recycling

Green building practices incorporate effective waste management strategies. This includes the implementation of waste segregation systems, recycling programs, and construction waste reduction techniques. By minimizing waste generation and promoting recycling, green buildings contribute to a circular economy and reduce the burden on landfills [9].

Indoor Environmental Quality

High indoor environmental quality is a key component of a green building's commitment to its residents' health and happiness. This includes the use of non-toxic building materials, proper ventilation, the elimination or reduction of indoor air pollutants, and the maximisation of natural light. These kinds of improvements make for happier and more productive occupants by making their living and working spaces safer for them.

1.3 Green Building Certifications and Rating Systems

The Indian Green Building Council (IGBC)

Green Building Rating System is a recognised benchmark for assessing building sustainability. They encourage green development and give a clear way to measure a project's environmental effect. This system also covers the various typologies of buildings in India as follows [8].

Green homes

Includes individual residential units such as apartments, villas, and independent homes. The major thrust is on efficiency of energy, conservation of water, management of waste and environment quality of indoors in houses.

Green building design and construction

This incorporates all types of non-residential buildings, including commercial, institutional, and industrial structures. It analyses the sustainability parameters construction and design phase, comprising selection of materials, site and efficiency of energy.

Green building operations & maintenance

It evaluates the current practices and performance of existing buildings in terms of sustainability. It consists of metrics for efficient water and energy consumption, management of waste, air quality of indoors, and overall maintenance of building.

Green townships

Its focus is on infrastructure, sustainable planning, that propagates environment friendly and healthy living environment in townships.

Green cities

Its focus extends to green city or urban area development encompassing sustainable planning, management of wastes, transportation infrastructure improving the overall liveable conditions.

Green existing buildings

It targets the repair and modification of existing buildings in order to make them eco-friendlier and energy efficient.

Green factory buildings

Its focus is on industrial buildings and manufacturing facilities, propagating reduction in waste, efficiency of resources resulting in sustainability practices in the industrial sector.

Green healthcare facilities

It incorporates ensuring the sustainable and environmental standards in healthcare buildings.

Green schools

This focuses on environment friendly practises in educational buildings ensuring a healthy learning environment.

Green railway stations

It encompasses for railway stations design and operations the sustainable and green practices.

Each of the typologies/categories mentioned above have a certain guideline to follow and get the certification from IGBC.

Other than IGBC there are other ratings and certifications as follows [10].

Green Rating for Integrated Habitat Assessment (GRIHA)

It is an indigenous green building rating system developed by the Indian Green Building Council (IGBC). GRIHA focuses on evaluating the ecological impact of buildings and aims to minimize resource consumption, reduce waste generation, and create healthier living environments. It assesses parameters such as site selection, energy efficiency, water conservation, waste management, and indoor air quality to determine the overall sustainability of a building.

Leadership in Energy and Environmental Design (LEED)

The U.S. Green Building Council (USGBC) devised a method for green building certification known as Leadership in Energy and Environmental Design. A foundation for creating, erecting, and running sustainable buildings is provided by LEED. There is a heavy focus on using eco-friendly materials, maintaining a healthy interior climate, using as little energy and water as

possible, and creating a low-impact outdoor space. Buildings may achieve varying levels of Leadership in Energy and Environmental Design (LEED) certification depending on how many points they get in various areas.

Building Research Establishment Environmental Assessment Method (BREEAM)

Originated from UK, it assesses factors like water, ecology, material and energy in buildings and infrastructure projects.

Green Star

Conceived by the Green Building Council of Australia (GBCA), it is prominently used in Australia and New Zealand. It includes sustainability factors like indoor environment quality, energy, materials and water in different building categories.

Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB)

It is German sustainable building council rating system that includes functional, sociocultural, economic and environmental factors in construction and processes.

Excellence in Design for Greater Efficiencies (EDGE)

It is designed by International Finance Corporation (IFC), targeting the resource optimization in design and construction with focus on materials energy and water in emerging markets.

Green Mark

It is a Singapore's Green Building Rating System, designed by Building and Construction Authority (BCA), evaluates water and energy efficiency to assess the environmental performance of buildings and infrastructure in Singapore.

Estidama Pearl Rating System

Conceived by Abu Dhabi Urban Planning Council, Estidama for targeting on sustainability in UAE by assessing the building performance criteria like ecological, energy and water.

Living Building Challenge

Designed by International living Future Institute with the mandate that the buildings will have to produce more energy than their consumption, use non-toxic, locally sourced materials and harvest and treat water on-site.

Comprehensive assessment system for building environmental efficiency (CASBEE)

It is a Japanese green building rating system that evaluates the performance of building on criteria's like; quality of indoor environment, emissions, and energy efficiency.

Well Building Standard

This is a modern rating system that evaluates the factors like, lightening, fitness, mental well-being, air quality to ensure the human health and well-being in built environment.

Green Globes

This is a North American certification, incorporating factors like, water, materials, energy while assessing buildings.

The above Green Rating systems may differ in terms of their regional applicability and level of austerity. The choice can be made in terms of best alignment with their project sustainability goals.

1.4 Comparisons of Pre-engineered building with conventional steel building

According to Radake et al. [11] the PEB technique is adaptable due to its good quality of construction with low cost and lightweight predesigned with prefabricated structure. Whereas, in traditional steel construction the designing is challenging because the foundation must be strong enough to support the weight of the structure.

Pre-engineered structures may benefit from the rapid development of software for design, cost calculation, detailing, drawings, etc. Such programmes do not exist for standard structures. Pre-engineered buildings have Symmetrical framing design which is efficient. Conventional building design is more time-consuming and provides fewer options for creating precise plans.

states that Pre-engineered structures employ built-up sections called Structural Members, which are 20-25% lighter than traditional construction methods. In these buildings International design codes such as AISC, AISI, MBMA and AWS are used all over the world, Whereas, in conventional Buildings only IS codes are used. The price per square meter is also 25% less to conventional buildings.

Sudhir et al. [13] mentions that Pre-engineered structures have a quicker turnaround time for delivery. After the design phase is complete, building time for 1500 MT is between 4 and 8 weeks. Furthermore, there are good number of options available at low cost for architectural aesthetics. However, when design is finalised, traditional structures take between 10 and 20 weeks to construct a 600 MT.

Further as per Mitaali et al. [14] Prefabricated structures may withstand earthquakes better than conventional ones, and their simple connecting system makes them easy to add onto. As opposed to the standard 50-meter clear span, pre-engineered building members may span up to 200 metres without any intermediate supports.

Prefabricated structures have standardised parts that can be swapped out for a fraction of the price of traditional construction, and their assembly is quicker and less labour-intensive. As opposed to using several suppliers, which may lead to problems with things like material quality and quantity, using only one is adequate for keeping PEB construction costs under control and on schedule.

1.5 Economic and social benefits

Green building practices offer substantial economic and social benefits. Energy-efficient buildings lead to reduced operational costs and energy savings, resulting in long-term financial advantages for building owners and occupants. Additionally, green buildings contribute to job creation, skill development, and local economic growth in sectors related to renewable energy, sustainable materials, and green technology.

2. LITERATURE REVIEW

2.1 Introduction

Steel construction industries is expanding speedily in almost all the parts of the world. The use of steel structures is not only economical in terms of time and cost but also environment friendly amid the risk of global warming. This section analyses the literature reviewed related to the:

a) Green rating system
b) Pre-engineered steel Building Technology

Literature review / work done by other researchers on both the two classification are described in the subsequent paragraphs.

2.2 Green rating system

According to Asdrubali et al. [15] Green rating system is a set of guidelines or criteria which is used for assessing and evaluating the performance and environmental sustainability of buildings. The purpose of designing them is to propagate and ensur the sustainable practices

Bungau et al. [16] highlighted the reasoned analysis about the Green building concept and its beneficial role to the stakeholders from designers to occupiers to the future generations.

Zheng et al. [17] defined green building concept as; "The ' green ' of ' green building ' does not mean the general sense of vertical greening, roof garden, instead, it represents a concept or symbol that refers to a building that is harmless to the environment. It can make full use of environmental natural resources, and is built without destroying the basic ecological balance of the environment. It can also be called sustainable development buildings, ecological buildings, natural buildings." Green building is a building of excellence, which conserve resources, safeguard the environment, diminishes pollution, grant people with healthy, suitable and productive use of space, and enhances the kinship between man and nature.

Singh, et al. [18] mentioned that the green building process considered environmental factors at every step. The method considered the building's impact on the environment as a whole, as well as its impact on the environment at each stage of its lifecycle (design, construction, operation, and maintenance). The research aimed to determine which sustainable construction materials have the greatest potential to slow down environmental deterioration and produce healthy structures that can last for generations. Since buildings were responsible for 40 percent of all carbon emissions, the researcher goes on to explain why green construction methods had a unique chance to significantly contribute to new worldwide carbon reduction goals.

A. Chaturvedi [8] studied a review on sustainable development by constructing green buildings in India and found that construction has evolved since the late 20th century. With population expansion, housing demand must be fulfilled with all resources. Humanity's energy supplies are few and diminishing. Because demand exceeds supplies, this will have a major effect. Resources will be exhausted, creating major issues. This situation has various solutions. Energy-efficient green building construction may replace conventional construction. Green buildings cost more to create but less to maintain. This study examines green construction facts and trends and compares sustainable and conventional building.

Byravan et al. [19] studied Quality of Life for all a sustainable development framework for India's climate policy reduces greenhouse gas emissions, development paths and policies affect GHG emissions and climate change adaptation. Institutional and technical lock-in from key policy choices and large-scale expenditures may also limit future possibilities. Still, research and policy divisions have frequently put development strategy and climate change mitigation in conflict. However, there has been much examination of their connections. The worldwide scientific community has suggested a SD framework for mitigation since the IPCC's Third Assessment Report. SD might also enable a climate strategy that appeals to stakeholders in diverse industries.

Sheth, et al. [20] studied, Sustainable building materials used in green buildings. Sustainable development includes using sustainable materials. In 1987 Research conducted by the World Commission on Environment and Development, widely used the phrase "The Future We Share" which means that with sustainable development, present needs are met without jeopardising those of the future. The principles of sustainable development were first discussed at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. John Elkington's approach for sustainable development included economic growth, social justice, and ecological preservation. A green structure will last for a long time. Materials, energy, water, indoor air quality, waste reduction, HVAC design, and site planning all have a role in the overall greenness of a building. The material effectiveness and environmental ethos of green materials are discussed in this research.

Tathagat et al. [21] studied Role of Green Buildings in Sustainable Construction Need Challenges and Scope in the Indian Scenario, found and Climate change, driven by greenhouse gases like carbon dioxide, is one of the biggest challenges of the 21st century. Due to strong industrialisation, urbanisation, population expansion, and IT development, India and China have also increased their share of world energy consumption. Modern cities absorb 40–45% of energy from buildings. Improving efficiency limits their usage, reducing greenhouse gas

emissions and fossil fuel depletion. The construction industry has approximately 50% savings potential and might help fulfil global energy consumption and climate change. With energy-efficient methods, more effective techniques are required to urge or coerce higher efforts, particularly from Kyoto Protocol signatories. This scientific article examines energy efficiency in green buildings in India to minimise energy consumption and greenhouse gas emissions (GHG). It also highlights the advantages of green construction and government and local incentives for GRIHA-certified green buildings.

llen, J.G et al. [22] concluded that According to the available scientific literature, green buildings have higher levels of both objectively measured and subjectively experienced interior environmental quality and health. For indoor environmental quality, green buildings had lower levels of VOCs, formaldehyde, allergens, ETS, NO2, and PM. Many of these environmental contaminants that have been linked to adverse health effects are explicitly addressed in green building design credits, so these early findings suggest that the design elements targeted at improved IEQ translate to significant reductions in actual exposure. Building acoustics was the one IEQ parameter that did not consistently score better in green buildings; in several studies, participants reported lower satisfaction with noise.

Bhattarai et al. [23] concluded that educed energy and water used in green buildings is a gift to society since it allows for increased production without jeopardising the health and safety of the building's inhabitants. This means that if this idea is put into practise successfully, it will benefit the greatest number of people possible.

Geelani et al. [24] studied Green Building Development for Sustainable Environment with Special Reference to India, discovered and Building techniques and materials have changed. Energy, long-distance transportation, raw materials, recycling, safe disposal, environmental effect, and long-term sustainability are all factors in the production of modern construction materials. By improving the site, design, construction, operation, maintenance, and removal of any new building material, energy expenditure, recycling, biodegradable, environmental, and sustainability issues related to future demand can be reduced in buildings' negative effects on human health and the environment. Green building advocates resource-conserving construction practises and products that won't harm the environment, building occupants, labourers, the general public, or future generations. The use of land, site impacts, interior environment, energy and water consumption, solid waste, and building material lifetime effects are all addressed in sustainable construction. Greenhouse gas emissions and energy usage would rise without immediate action to reduce the industry's environmental impact.

R. Shrikanth and D. S. N. Raju [25] studied contemporary green marketing brief reference to Indian scenario and observed that in the contemporary period of globalisation, it is difficult to retain customers and consumers and protect the environment, which is the greatest necessity. Environmental contamination is a commercial buzzword. Consumers also understand global warming and pollution. Green marketing is an essential method for sustainable development in India and other developing and industrialised nations. This study emphasises green marketing's idea, necessity, and significance. To comprehend the value of green and sustainable management, data must be gathered from different sources, including books, journals, websites, and newspapers. The paper explores what green marketing is and how it may help a company compete. It addresses green marketing's biggest challenges. The report discusses green marketing's difficulties and prospects in the Indian market. Why firms are embracing it and the future of green marketing.

According to Umar et al. [26] the term sustainable building materials refers to those that are locally produced and sourced, reducing transportation expenses and carbon dioxide emissions; recyclable; thermally efficient; energy-needing less; utilising renewable resources; producing fewer harmful emissions; and economically viable.

Allen Matkins Green Building Survey, Constructive Technology Group [27] the results of the survey were surprising regarding green construction. The survey captures the current attitudes of the professionals involved in green building and LEED certification Majority of the respondents support the Green and Sustainable construction and also perceived the worth of LEED certification process.

Abbaszaheh et al. [28] presented an overview of the findings from a major assessment of office buildings' interior environmental quality, contrasting green with non-green structures. Workplace thermal comfort and air quality were rated higher by the majority of occupants in green buildings compared to non-green buildings.

2.3 Pre-engineered steel building technology

Light gauge metal standing seam roof panels and steel purlins are fastened together between rigid frames to provide a pre-engineered building's (PEB) signature look. It is constructed locally from prefabricated components [29]. As a result of its speedy construction, the PEB method is widely used in India.

Shaik, Kalesha et al. [4] discussed about the technical parameters with design codes and standards. They further elaborate that the pre-engineered buildings are designed on American or Indian codes of Practice based on customer requirements. AISC-89 and AISC-2005 are used for primary members, MBMA96 is used for Load combinations, AISI 1996 is used for cold

formed members, IS 800 - 1984 and IS 800 - 2007 are used for serviceability conditions, IS 2062 is used for design of hot rolled medium and high tensile structural steel miscellaneous members. PEB Steel framed design as per IS 875 part III –1987 used for wind analysis and seismic analysis as per IS 1893 2002. Several software's used to create, check and publish in digital formats like, model calculations, construction drawings, GA and anchor bolt drawings, shop drawings, and bill of materials. To produce quality design and diagrams for a PEB, the software used are MBS, STAAD-ProV8i, Tekla-Structures and Auto CAD.

Sah et al. [12] concluded that from an architectural point of view, PEB definitely produces superior results, because to its vast clear spans and adaptability to future development. The findings also show that PEB construction is more long-lasting, eco-friendly, and cost-effective than CSB.

Thakare et al. [30] investigated the health and social benefits of the building industry and how those benefits might be maximised via the use of various materials. Materials used in green construction reduce greenhouse gas emissions, resource depletion, soil pollution, health concerns, and ozone depletion while also creating efficient, long-lasting buildings. For the sake of future generations and their quality of life, there is a pressing need to introduce eco-friendly goods.

S. Singh and H. Singh [31] concluded in their paper that Pre-engineered steel sections should be adopted for the construction of the buildings as they are not only economical (it saves steel) but also sustainable.

Chen, et al. [32] discussed the advantage of Prefabricated/pre-engineered buildings. It's more cost-effective to build, decorate, and put together structures using this method, and it meets the green building industry's stringent standards for doing so.

Saleem et al. [33] mentioned, that PEB building is eco-friendly since it requires less energy to build and less material is wasted during the building process (mostly due to the absence of welding and cutting). In contrast to CSB, where everything is built on-site without any supervision whatsoever, a great deal of material is wasted during the fabrication process when done in a factory.

A. Chaturvedi [8] studied a review on sustainable development by constructing green buildings in India and found that construction has evolved since the late 20th century. With population expansion, housing demand must be fulfilled with all resources. Humanity's energy supplies are few and diminishing. Because demand exceeds supplies, this will have a major effect. Resources will be exhausted, creating major issues. This situation has various solutions. Energy-efficient green building construction may replace conventional construction. Green

buildings cost more to create but less to maintain. This study examines green construction facts and trends and compares sustainable and conventional building.

Ragheb et al. [34] described, Green Architecture, as sustainable architecture or green building, which is the study, practise, and aesthetics of creating structures that minimise their impact on the natural environment. The goal of green architecture is to reduce the building's environmental impact by minimising its energy consumption, water use, and trash production during its life cycle.

Rao et al. [35] cited that, when compared to traditional steel frames, pre-engineered steel structures are far more economical, long-lasting, and eco-friendly. The use of prefabricated steel buildings helps alleviate some of the causes of global warming and pollution, which is good news for the planet's health.

Ramancharla et al. [36] studied the comparison of the weights between the Indian codes and American codes and found that American codes provide lighter weight steel as compared to Indian codes.

Governments in developing nations should take the lead in raising public awareness and educating the populace, then drafting fundamental guidelines for widespread implementation. Building certification and registration procedures also need to be defined by the government at a high level.

3. RESEARCH GAPS

3.1 Research Gaps from literature review

Based on the review conducted on the sustainable development of green building in India, several research gaps can be identified. These research gaps highlight areas where further investigation and study are needed to enhance the understanding and implementation of sustainable green building practices in the Indian context. The research gaps include:

a) Implementation of PEB (Constraints)

Constraints regarding the structural integrity was found in terms of PEBs performance under extreme environmental conditions of hurricanes, earthquakes and severe weather conditions. Constraints were also seen in terms of thermal performance of PEBs and use of innovative technologies to enhance their energy efficiency such as smart insulation or passive design strategies. Limited research information was available on cost benefit analysis like initial cost, long term maintenance and life cycle costs. There was no specified research found on the application of green building rating framework in PEB structure [8].

b) Sustainability of PEB

Research on the sustainability of Pre-Engineered Buildings is extremely essential as these buildings are becoming more famous due to their efficiency and cost-effectiveness. However, there are several research gaps which needs immediate attention in order to enhance the sustainability of PEBs. There is a need for more comprehensive Life cycle assessment process to understand environmental impact on construction, extraction of material, operation and manufacturing to have a comprehensive view of PEB sustainability [37]. Further gaps were found in studies related to developing strategies to enhance resilience of PEB to climate changes and natural disasters like variations in temperature, earthquakes, flooding, hurricanes [1]. Further research has to be done more on integration of green materials and renewable energy technologies to reduce carbon footprints of PEBs. The most critical research gap found is the lack of analysis of the existing regulations and policies in supporting and propagating sustainable practices in PEB construction, and recommending improvements or new policies if required.

c) Credits in green rating systems for PEB

The Green rating system often presents lack of specific PEB related credits which can focus more on its unique characteristics and construction processes. Further research gaps were also found in exploring the usage of advanced energy modeling and simulation tools for PEBs to precisely evaluate the performance of energy resulting in more accurate energy related credits.

Future researches are required to explore best practices for waste management in construction specifically in PEB projects to control waste and earn credits for reduction of waste and recycling [16].

Addressing these research gaps would contribute to the knowledge base on sustainable development of green buildings in India, providing insights and recommendations for policymakers, industry professionals, and researchers to foster the adoption.

4. DESCRIPTION OF BROAD AREA

4.1 Green Building Quotient of Pre-Engineered Buildings

The Green Building Quotient of Pre-Engineered Buildings (PEBs) refers to the measurement of sustainability and environmental performance of these specific types of structures. Prefabricated steel buildings (PEBs) are constructed at a factory and transported to the construction site for final assembly. The Green Building Quotient is an environmental and energy efficiency rating system for PEBs that considers performance across the whole building's lifespan. Use of renewable energy sources, water efficiency, indoor air quality, trash reduction, and energy usage are all considered [33].

The Green Building Quotient is an indicator that uses these criteria to push for more eco-friendly procedures in building design, construction, and operation. To reduce their impact on the environment, it promotes the use of sustainable resources, efficient processes, and cutting-edge technology. By achieving a high Green Building Quotient, PEBs can contribute to reducing greenhouse gas emissions, conserving resources, and creating healthier indoor environments. They can also showcase the commitment of stakeholders towards sustainable development and responsible building practices [34].

4.2 The Need for Sustainable Development in India's Construction Sector

Rapid urbanisation, population growth, and rising infrastructure needs are fuelling India's building boom. This expansion creates severe environmental issues and economic opportunity. To reduce environmental damage and promote long-term social and economic well-being, India's construction industry needs sustainable growth. The construction sector consumes natural resources, energy, and water and generates waste and greenhouse gas emissions. Sustainable construction approaches, especially green building, are crucial to India's sustainable development aspirations. Green construction approaches reduce buildings' environmental impact throughout their lifespan. They encourage energy efficiency, water conservation, waste reduction, renewable materials, and healthy indoor settings. India may cut carbon emissions, save resources, increase energy security, and improve human well-being by adopting these building methods [36]. Sustainable building has major environmental advantages. Energy-efficient buildings cut energy consumption, lowering greenhouse gas emissions and fossil fuel usage. In water-stressed areas, rainwater collecting and smart plumbing may reduce water use. Sustainable building reduces waste and promotes recycling, creating a circular and resource-efficient economy. Sustainable building development has environmental, social, and economic benefits.

Green buildings improve tenant health and productivity. Sustainable practises also boost innovation, employment, and renewable energy and green technology investment. Aligning the building sector with global sustainability standards and addressing the changing demands of environmentally aware customers and stakeholders boosts its competitiveness. India has prioritised sustainable construction and green building principles in its national agenda. The government and industry associations have developed green building grading systems, financial incentives, and regulatory frameworks to promote sustainable construction. Construction sustainability scaling remains difficult. These include stakeholder awareness and education, green project finance, experienced specialists, and sustainable construction norms and laws.

5. OBJECTIVES OF THE STUDY/RESEARCH

After going through the intensive research, following research objectives were identified, the details of which are given under;

1. To evaluate the potential of Pre-Engineered Buildings as an environment friendly and sustainable construction solution.
2. To find out the extent of barriers faced by stakeholders for adopting Green Building design and construction for Pre-Engineered Buildings.
3. To compare the applicability of Rating frameworks in conventional concrete vs steel Pre-Engineered Buildings
4. To explore the emphasis of Green Rating for Pre-Engineered Buildings in different countries.
5. To recommend additional criteria and credits in established Rating framework in context of India.

6. METHODOLOGY TO BE ADOPTED

6.1 Research Problem

There are several considerations that go into a researcher's decision on the study approach to use. Considerations like these are influenced by a number of factors, such as the researcher's point of view, the specifics of the study subject, the present level of scientific research and ideas, and the larger social and political backdrop. A quantitative approach is often the most reliable way to verify a theory or identify the factors that contribute to an outcome. These results prompted the recommendation of a quantitative approach to this research.

6.2 Research Design

Research questions and objectives may be answered via the use of a data collection, measurement, and analysis technique in the study design. Because every researcher is unique, the best practises for doing research vary from one to the next. Both the studies are based on data and are descriptive in nature. Data from both primary and secondary sources will be collected.

6.3 Nature of Research

A systematic survey will be used in quantitative research to acquire data from the general public. When data can be represented numerically and mathematical manipulation is appropriate for researchers to forecast future occurrences or quantities, sampling techniques are used in quantitative research, such as consumer surveys. As a group, quantitative researchers are enthusiastic about the validity of their conclusions based on statistics. At the very least, that's what they're hoping for.

6.4 Data Collection

For certain variables, data collection is considered a systematic gathering and measuring technique that enables us to answer relevant questions and evaluate outcomes. The data will be collected by the help of self-administered questionnaires. The respondents will be home owners of green buildings (GRIHA certified), warehouses and builders, who tends to build the buildings using the green construction concepts.

Schematic framework to show hypothetical relationship among variables under study:

Independent variables:

1. Energy efficiency
2. Materials sourcing
3. Water usage
4. Indoor air quality

5. Site selection and land use
6. Innovation and design process

Dependent variable:

1. Green rating of Pre-engineered steel building

Mediating variables

1. Cost considerations
2. Regulatory compliance

Contextual variables

1. Building type and use
2. Geographic location
3. Market demand and perception
4. Stakeholder engagement

This schematic framework as shown in figure outlines the key independent variables (factors within the green rating framework), the dependent variable (the green rating), as well as mediating variables (factors that may influence the relationship) and contextual variables (external factors that provide context to the study).

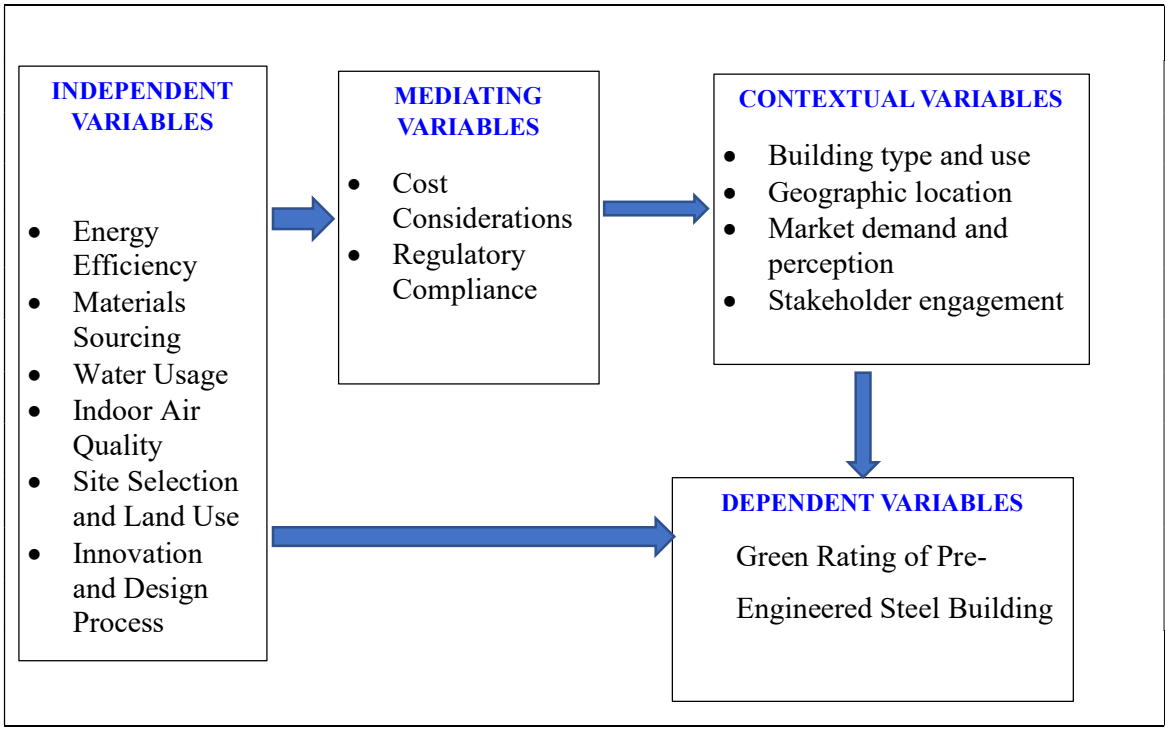

Fig: 1 Schematic diagram showing the relationships between the variables

6.5 Area and sample size

The area for the research will be National Capital Region i.e., Delhi and its adjoining districts which are categorised as NCR in India.

Sample Size:

The sample size for the study will have more than 100 respondents.

6.6 Data collection methods

There are many ways to collect data, but one of the most common is by the systematic gathering of information on a certain variable and its subsequent measurement and evaluation. Regardless of the method used, the goal is to gather data that is accurate and truthful. Any data collecting effort should aim to gather high-quality evidence that can be analysed to answer research questions convincingly.

Primary data

The main data will be gathered via the use of a questionnaire, in which the questions will be organised in a logical manner for gathering information on pre-engineered buildings.

Secondary data

Secondary data analysis may save a great deal of time and effort that would otherwise be spent on collecting data, and it can provide researchers with access to larger and more accurate data sets than they would be able to get on their own.

Secondary data will be gathered from a variety of sources:

- Internet sites, journals, media, and research papers.
- Libraries, academic results, and institutional observations, among other things.

6.7 Data analysis

Analysing and interpreting data is a multi-step process that begins with a review of the data and ends with a recommendation for action. Data analysis encompasses a wide variety of methodologies and approaches, including a wide range of business, scientific, and social science disciplines.

According to the analysis, a whole component is disassembled and tested separately. The process of turning raw data into useful information for decision-making is known as data analysis. To answer questions, assumptions, or concepts, data are acquired and analysed.

7. EXPECTED OUTCOMES OF THE RESEARCH

The proposed/expected outcome of the research on the green rating framework for environment friendly Pre-engineered buildings in India can be summarized as follows:

1. Enhanced Understanding: The research aims to provide a comprehensive understanding of the current state of green rating framework in India, analysing existing initiatives, policies, and the role of organizations promoting sustainable practices with the use of PEB.
2. Identification of Challenges: The research will identify and analyse the challenges hindering the widespread adoption of Pre-engineered steel building practices in India, such as lack of awareness, high costs, and limited availability of skilled professionals.
3. Knowledge Dissemination: The research aims to raise awareness about the benefits of green buildings with regards to use of PEBs as compared to conventional buildings, highlighting their positive impacts on energy conservation, indoor air quality, and occupant health and productivity.
4. Future Scenarios and Innovations: The research will explore future scenarios for green building development, emphasizing the integration of renewable energy sources, circular economy principles, and innovative technologies.
5. Recommendation for credits in GRIHA certification exclusively for PEBs.

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